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ABSTRACT

This paper describes strategies that can be used in commercial buildings to temporarily reduce electric load in response to electric grid emergencies in which supplies are limited or in response to high prices that would be incurred if these strategies were not employed. The demand response strategies discussed herein are based on the results of three years of automated demand response field tests in which 28 commercial facilities with an occupied area totaling over 11 million $ft.^2$ were tested. Although the demand response events in the field tests were initiated remotely and performed automatically, the strategies used could also be initiated by on-site building operators and performed manually, if desired. While energy efficiency measures can be used during normal building operations, demand response measures are transient; they are employed to produce a temporary reduction in demand. Demand response strategies achieve reductions in electric demand by temporarily reducing the level of service in facilities. Heating ventilating and air conditioning (HVAC) and lighting are the systems most commonly adjusted for demand response in commercial buildings. The goal of demand response strategies is to meet the electric shed savings targets while minimizing any negative impacts on the occupants of the buildings or the processes that they perform. Occupant complaints were minimal in the field tests. In some cases, "reductions" in service level actually improved occupant comfort or productivity. In other cases, permanent improvements in efficiency were discovered through the planning and implementation of "temporary" demand response strategies. The DR strategies that are available to a given facility are based on factors such as the type of HVAC, lighting and energy management and control systems (EMCS) installed at the site.

Background

Power requirements on the electric grid are in constant flux based on the demand of the devices connected to it. This demand varies based on time-of day, weather and many other factors. Traditionally, the supply is varied to meet the demand by increasing or decreasing electric generation capacity. Conversely, demand response (DR) can be defined as short-term modifications in customer end-use electric loads in response to dynamic price and reliability information.

As electric demand increases, generation costs increase in a non-linear fashion. A price spike caused by high demand on a hot summer afternoon would be an example of price information that might be used to initiate short-term modifications in customer end-use electric loads. A scenario in which a power plant failed unexpectedly would be an example of where short-term modifications in customer end-use electric loads could help other on-line plants manage the demand thereby increasing system reliability and avoiding blackouts.

Many electric utilities across the United States have implemented programs that offer financial incentives to ratepayers who agree to make their electric loads more responsive to pricing and/or reliability information. These programs are most prevalent for commercial and industrial customers in utility districts with known capacity or transmission constraints.

Recent studies have shown that customers have limited knowledge of how to develop and implement DR control strategies in their facilities (Goldman et al., 2004). Another barrier to participation in DR programs is the lack of systems that help automate the short-term modifications or strategies required during DR events.

This paper focuses on strategies that can be used to enable demand response in commercial buildings (i.e., to make short-term modifications to their end-use equipment).

Results of Field Tests

The strategies discussed herein are based on the results of a series of field tests conducted by the PIER Demand Response Research Center. While the tests focused on fully automated electric demand response, some manual and semi-automated demand response was also observed. The field tests included 28 facilities, 22 of which were in Pacific Gas & Electric territory. The other sites were located in territories served by Sacramento Municipal Utility District, Southern California Edison, City of Palo Alto Utilities and Wisconsin Public Service. The average demand reductions were about 8% for DR events ranging from three to six hours.

Table 1 shows the number of sites that participated in the 2003, 2004, and 2005 field tests along with the average and maximum peak demand savings. The electricity savings data are based on weather sensitive baseline models that predict how much electricity each site would have used without the DR strategies. Further details about these sites and the automated DR research are available in previous reports (Piette et al., 2005a and 2005b).

Table 1: Average and Maximum Peak Electric Demand Savings during Automated DR Tests.

Results by Year	Number of sites	Duration of Shed (Hours)	Average Savings (%)	Max. Savings (%)
2003	5	3	8	28
2004	18	3	7	56
2005	12	6	9	38

Figure 1 shows various DR strategies that were used in field tests and the frequency of each. The tests included building types such as office buildings, a high school, a museum, laboratories, a cafeteria, data centers, a postal facility, a library, retail chains, and a supermarket. The buildings range from large campuses, to small research and laboratory facilities.

Figure1. Frequency of various DR Strategy Useage.

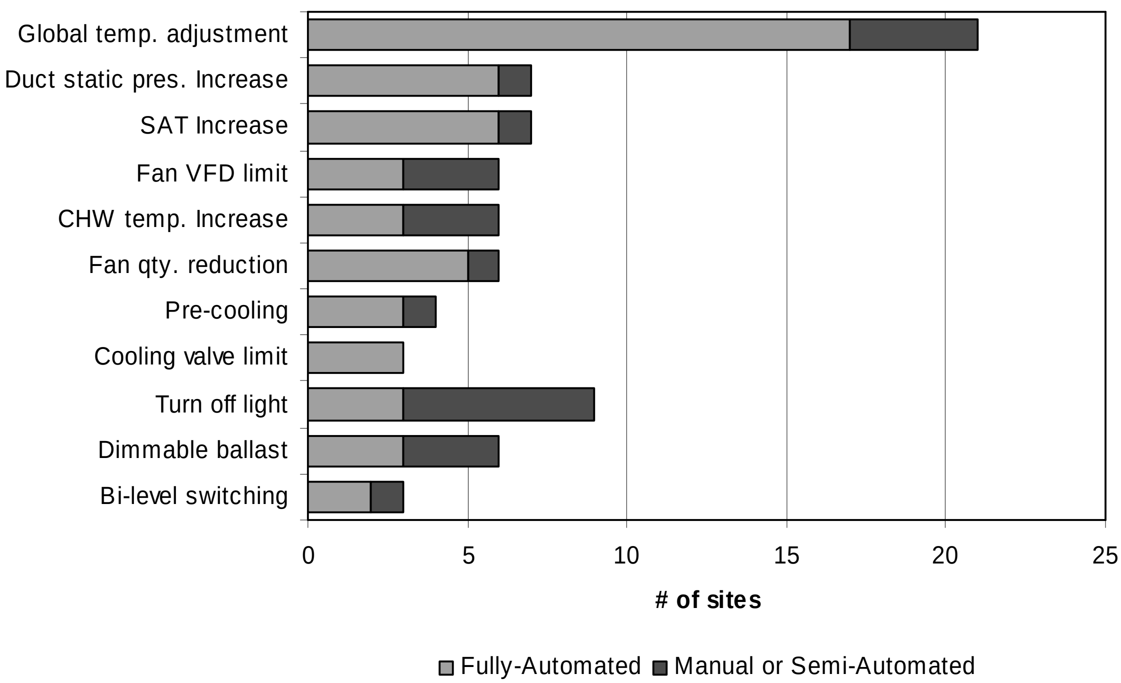
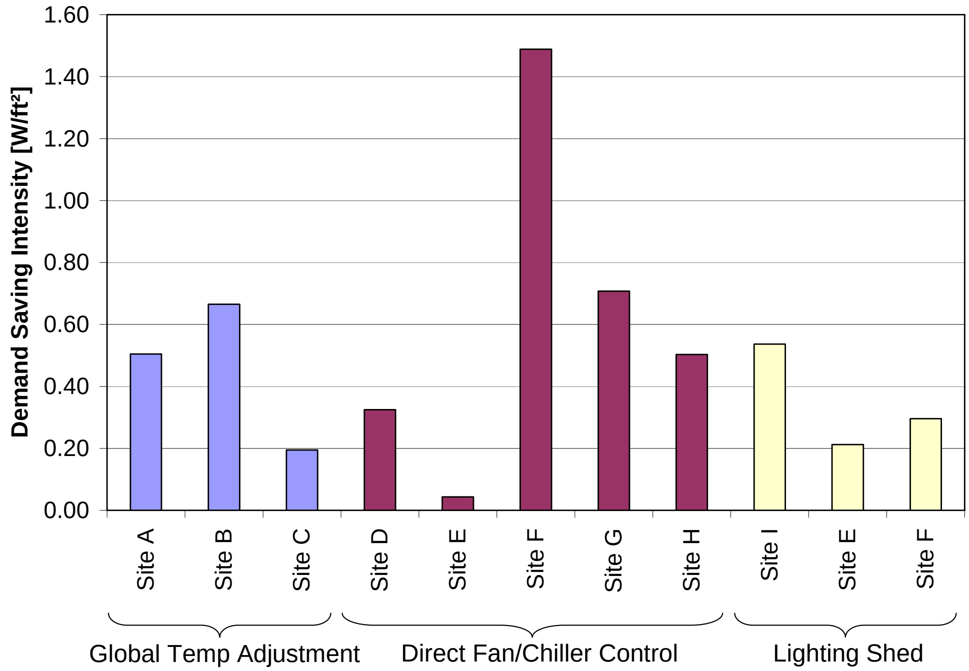


Figure 2 shows various DR strategies that were used in field tests and the Demand Saving Intensity (W/ft2) by Shed Strategy. The values shown are average savings over one hour. Though the sample size is not large enough to generalize shed savings by strategy, it is clear that each of the three shed categories listed has the potential to shed about 0.5 W/ft2. Most of the DR HVAC strategies we've examined provide considerably greater savings on hotter days and the data in Figure 2 were from a mild day. Lighting strategies are not weather dependent.

Figure2. Demand Saving Intensity (W/ft2) by Shed Strategy on November 5, 2004.



Concepts and Terminology

Energy Efficiency: Energy efficiency can lower energy use without reducing the level of service. Energy efficiency measures are part of normal operations to permanently reduce usage during peak and off-peak periods. In buildings, energy efficiency is typically achieved through efficient building designs, the use of energy efficient equipment and through efficient building operations. Since energy efficiency measures are a permanent part of normal operations, they are typically considered separate from demand response which involves short term modifications to normal operations. However, some energy efficiency measures such as the use of variable frequency drives (VFDs) on electric motors can enable both energy efficiency and temporary demand response modes when called to do so.

Daily Peak Load Management: Daily peak load management is done in many buildings to minimize peak demand charges and time-of-use rates. Strategies that temporarily modify the operation of HVAC or lighting systems are often used to implement daily peak load management. Decisions about when to initiate daily peak load management are typically made by on-site staff or on-site automated equipment.

Demand shifting: is achieved by changing the time that electricity is used. Thermal energy storage is an example of a demand shifting technology. Thermal storage can be achieved with active systems such as chilled water or ice storage, or with passive systems such as pre-cooling the mass of a building (Xu, et al., 2005). Both daily peak load management and demand shifting are typically done to minimize peak demand and time-of-use rate charges.

Demand Response: Demand response (DR) can be defined as short-term modifications in customer end-use electric loads in response to dynamic price and reliability information. DR events are dynamic and temporary. They are driven by factors such as low electricity reserves, warm weather and grid conditions.

One of the key components of DR is that the pricing and reliability information known at the grid system or utility level must be transmitted and translated into load reducing actions at the end-use sites. Signaling methods used to inform facility operators of upcoming DR events include: phone calls, pagers, text messages and e-mail messages. Control signals are also used in some systems for direct signaling to energy management and control systems (EMCS) and control of electric loads. These digital control signals are broadcast using radio transmissions, power-line communications and the Internet.

DR can be implemented using various levels of automation. **Manual Demand Response** is performed by facilities staff physically turning off electric equipment after receiving notification of an upcoming DR event. **Semi-Automated Demand Response** is similar, but reduces facilities staff labor through use of a centralized control system with pre-programmed demand response strategies. **Fully-Automated Demand Response** enables remotely generated event initiation signals to control loads directly or to initiate pre-programmed demand response strategies at the site. Though Fully-Automated Demand Response is capable of functioning without human intervention, it is recommended that facility operators are kept informed of the process and have the ability to "opt-out" of a DR event, if desired.

Reduction in service: Demand response strategies achieve reductions in electric demand by temporarily reducing the level of service in facilities. Heating ventilating and air conditioning (HVAC) and lighting are the systems most commonly adjusted to achieve demand response savings in commercial buildings. The goal of demand response strategies is to meet the electric shed savings targets while minimizing any negative impacts on the occupants of the buildings or the processes that they perform. Occupant complaints were minimal in the field tests. In some cases, "reductions" in service level actually improved occupant comfort or productivity. Such cases can be caused by over-cooling that occurs in some buildings during normal operation. In other cases, permanent improvements in efficiency were discovered through the planning and implementation of "temporary" demand response strategies. The DR strategies that are available to a given facility are based on factors such as the type of HVAC, lighting and energy management and control systems (EMCS) installed at the site.

Shared burden: DR strategies that share the burden evenly throughout the facility are least likely to have negative effects on building occupants. For example, if it were possible to reduce lighting levels evenly throughout an entire facility by 25% during a DR event, impacts to occupants may be minimal. However, turning off all of the lights in one quadrant of an occupied space would not be acceptable. In HVAC systems, strategies that reduce load evenly throughout all zones of a facility are superior to those that allow certain areas (such as those with high solar gains) to substantially deviate from normal temperature ranges.

By combining savings from sheds in HVAC and lighting (and other loads, if available), the impact on each system is minimized and the savings potential is increased.

Closed loop control: Comfort is maintained in modern buildings through the use of closed loop control of HVAC systems. Sensors are used to measure important parameters such as temperature and pressure. Controllers adjust actuators such as dampers or valves to maintain the desired setpoints for those parameters. The effect of the actuators on the controlled zone or system is measured by the sensor, hence “closing the control loop”. Control sub-systems for which there is no feedback from sensors are known as “open loop” controls.

In order to maintain predictable and managed reductions of service during DR events, strategies should maintain the use of closed loop controls in HVAC systems.

Granularity of control: For the purposes of DR control in buildings, the concept of granularity refers to how much floor area is covered by each controlled parameter (e.g., temperature). In HVAC systems, the ability to easily adjust the temperature setpoint of each occupied space is a highly granular way to distribute the DR shed burden throughout the facility. Less granular strategies such as making adjustments to chillers and other central HVAC equipment can provide effective shed savings, but can cause temperature in some zones to drift out of control. Granularity of control can also allow building operators to create DR shed behaviors that are customized for their facility. An example of this would be to slightly increase all office zone temperature setpoints, but leave computer server room setpoints unchanged.

Resolution of control: In HVAC systems, parameters are controlled with great resolution. In many systems temperature setpoints can be adjusted by as little as 0.1ºF. Although some modern lighting ballasts can adjust individual lamps in less than 1% increments, most commercial lights are only capable of being turned on or off. Additional information is provided in the "Lighting Based DR Strategies” section below.

Rebound: At the end of each DR event, the effected systems must return to normal operation. When lighting strategies are used for DR, normal operation is regained by simply re-enabling all lighting systems to their normal operation. Lights will come back on as commanded by time clocks, occupancy sensors or manual switches. There is no reason for lighting power to jump to levels that are higher than normal for that period.

However, without special planning HVAC systems tend to use extra energy following DR events in order to bring systems back to normal conditions. Extra energy is used to remove heat that is typically gained during the reduced service levels of the DR event. This post DR event spike in demand is known as “rebound”. To minimize high demand charges and to reduce negative effects to the electric grid, rebound should be reduced or minimized through use of a strategy that provides a graceful return to normal operation. The simplest case is where the DR event ends or can be postponed until the building is unoccupied. If this is not possible, strategies that allow HVAC equipment to slowly ramp up or otherwise limit power usage during the return to normal period should be used.

HVAC Based DR Strategies

HVAC systems can be an excellent resource for DR shed savings for several reasons: 1) HVAC systems create a substantial electric load in commercial buildings, often more than 1/3 of the total. 2) The “thermal flywheel” effect of indoor environments allows HVAC systems to be temporarily unloaded without immediate impact to the building occupants. 3) It is common for HVAC systems to be at least partially automated with EMCSs.

However, there are technical challenges to using commercial HVAC systems to provide DR sheds. These systems are designed to provide ventilation and thermal comfort to the occupied spaces. Operational modes that provide reduced levels of service or comfort are rarely included in the original design of these facilities. To provide reliable, repeatable DR sheds it is best to pre-plan and automate operational modes that will provide DR savings. The use of automation will reduce labor required to implement DR operational modes when they are called. In addition, timeliness of the response will typically be improved.

HVAC based DR strategies recommended for a given facility vary based on the type and condition of the building, mechanical equipment and energy management and control system (EMCS). Based on these factors, the best DR strategies are those that achieve the aforementioned goals of meeting electric shed savings targets while minimizing negative impacts on the occupants of the buildings or the processes that they perform. The following DR strategies are prioritized so as to achieve these goals:

1. Global temperature adjustment (GTA) of zones
2. Centralized adjustments to the air distribution and/or cooling Systems

All HVAC based DR strategies outlined in this paper allowed zone temperatures to drift outside of normal ranges. However, the rate at which the temperatures drifted was well below the rate of Acceptable Temperature Change defined in ASHRAE Standard 55-2004. DR strategies used to return the HVAC system to normal operation should be designed for a similarly gradual rate of change. In addition to the comfort benefits outlined in the ASHRAE standard, strategies that slowly return the system to normal have the additional benefit of limiting rebound spikes as described previously.

Global Temperature Adjustment of Zones

Description: Global Temperature Adjustment (GTA) of occupied zones is a feature that allows commercial building operators to easily adjust the space temperature setpoints for an entire facility from one command from one location. Typically, this is done from a screen on the human machine interface (HMI) to the energy management and control system (EMCS). In field tests, GTA was shown to be the most effective and least objectionable strategy of the five HVAC shed strategies tested.(Piette et al., 2005a). It is most effective because it reduces the load of all associated air handling and cooling equipment. It is least objectionable because it shares the burden of reduced service level evenly between all zones. GTA based DR strategies can be implemented either manually by building operators or automatically based on remote signals.

Typical implementation: GTA is typically implemented by broadcasting a signal from the central EMCS HMI server to the all final space temperature control devices distributed throughout the facility. Upon receipt of a global signal from the central EMCS server, the final space temperature control devices interprets the signal and reacts accordingly (e.g., DR Mode Stage-1 means increase space cooling setpoints 3°F and decrease space heating setpoints 3°F).

Final space temperature control devices suitable for GTA include:

- Space temperature controllers that adjust variable air volume (VAV) terminal box dampers (all types) (e.g., VAV boxes).
- Space temperature controllers that adjust hot water heating coil valves or chilled water cooling coils (e.g., fan coil units, CAV multi-zone heating and cooling coil valves).
- Space temperature controllers that adjust capacity of heat pumps or direct expansion (DX) units.

To avoid an unwanted increase in heating energy, heating setpoints should remain the same or be reduced during GTA mode.

Mode Transitions: In the most basic implementation, upon receipt of a DR signal the GTA enabled system will increase space cooling setpoints in one or two steps (two step increase shown in table 2). Upon entering a DR mode (e.g., moderate shed), the global temperature setpoints will be increased and load on the air distribution and cooling systems will decrease.

More advanced implementations can adjust setpoints to follow linear or exponential curves (Xu, et al., 2005). Though more difficult to program, these strategies can provide added flexibility in creating shed profiles that are customized to provide optimal consistency or duration for a given facility.

Decay of Shed Savings: Over time, internal and external heat gains will increase zone temperatures until they exceed the new DR setpoints, causing fan and cooling systems to ramp back up. This phenomenon, known as "decay" of shed savings, can be prevented by further increasing the zone cooling setpoints to new levels (e.g., high shed). After a certain time duration, which varies by building type, weather and other factors, the shed savings will decay to the point where additional setpoint increases are not viable in an occupied building. In field tests, successful sheds of up to six hours have been performed without substantial impact on commercial building occupants.

Absolute vs. Relative implementation: Global Temperature Adjustment (GTA) may be implemented on either an absolute or relative basis (table 2). An absolute implementation of GTA allows the operator to set the space temperature setpoints for the entire facility to absolute values (e.g., heating setpoints at all final space temperature control devices = 68ºF and cooling setpoints at all final space temperature control devices = 76ºF). A relative implementation of GTA allows the operator to adjust the space temperature setpoints for the entire facility to new values that are offset from the current values by a relative amount (e.g., heating setpoints at all final space temperature control devices should decrease 2ºF from current values and cooling setpoints should increase 2ºF from current values). A relative implementation of GTA is best suited for sites where "normal" setpoints vary throughout the facility. It ensures that temperature will not deviate more that a fixed amount from the customized normal setpoint for each zone.

Table 2: GTA Setpoint Adjustment – Example of absolute and relative implementations

DR Mode	Absolute Space Temp. Cooling Setpoints	Relative Space Temp. Cooling Setpoints
Normal	74°F (globally)	Varies per zone
Moderate Shed	76°F	Normal +2°F
High Shed	78°F	Normal +4°F

Factory vs. Field Implementations of GTA: Several manufacturers offer GTA as a standard feature in their EMCS products. In field tests, sites that used EMCS products from these vendors provided some of the largest sheds and required the least amount of set-up labor. For sites that have EMCS controlled space temperature zones, but lack GTA, it can typically be added in the field. To add GTA to an existing site, each EMCS zone controller must be programmed to "listen" for global GTA commands from the central EMCS system. In addition, the central system must be programmed to send GTA commands to all relevant zone controllers on the EMCS digital network. Typically GTA commands are sent in a global broadcast to all controllers simultaneously.

Impediments to using GTA Strategy: In field tests, sites that used HVAC shed strategies other than GTA usually did so because that feature was not available at their site. Reasons that GTA is not available include:

- Space temperature not controlled by EMCS (e.g., use of pneumatic controls in occupant zones).
- Space temperature is controlled by EMCS, but space temperature controllers do not include the GTA feature. (i.e., EMCS can adjust space temperature setpoints in each zone individually, but not globally). Adjusting each zone individually is too time consuming and error prone to use for DR purposes.

Evaluation of Global Temperature Adjustment of Zones: While the GTA DR strategy reduces the service level of the occupied spaces, it does so using a closed-loop control strategy in a highly granular fashion. This causes the DR shed burden to be evenly shared between all building occupants and keeps all zones under control. Since none of the zones are starved for airflow, there is no risk of ventilation rates dropping below specified design levels. If global temperature adjustment (GTA) of zones is available, it is the recommended HVAC DR shed strategy for commercial buildings.

Air Distribution and Cooling System Adjustment

In systems for which the aforementioned global temperature adjustment of zones is not an option, strategies that make temporary adjustments to the air distribution and/or mechanical cooling systems can be employed to enable demand response. Depending on the mechanical systems in place at a given facility, the following demand response strategies may be used:

Duct Static pressure setpoint reduction: For variable air volume systems, duct static pressure (DSP) is typically measured in the supply duct. The EMCS modulates the speed of the fan or the position of inlet guide vanes to maintain a defined duct static pressure setpoint at the measured location. The “normal” DSP SP at the measured point should be high enough to provide enough pressure for each terminal VAV box to function properly. In an ideal system, the DSP SP would be set just high enough to meet the pressure requirements of the VAV terminal box of greatest demand. But since the box of greatest demand, and its associated pressure requirement are in constant flux, sub-optimal, yet substantially simpler strategies are usually used to control duct static pressure. Typically DSP is measured at a single location about two-thirds of the way down the duct system. The DSP SP is set to a fixed value that is high enough to meet the needs of the box of greatest demand during design load conditions. During less demanding conditions energy is wasted due to losses associated with the DSP SP being higher than necessary to meet the demands of the VAV terminal boxes.

Fan energy and cooling energy can be reduced during DR events by reducing the duct static pressure setpoint. This strategy is effective for three reasons:

1. The “normal” DSP SP is often higher than necessary. By reducing the DSP SP, some shed savings is provided without any reduction in comfort or service to the occupants.
2. Additional shed savings occurs when the DSP SP is set low enough to cause some VAV terminal boxes to “starve” from lack of air pressure. This reduction in service causes less air flow through the fans. There is some risk of ventilation rates dropping below specified design levels in some areas using this strategy.
3. When airflow drops below levels necessary to cool the space, electric load on the cooling system also drops.

Fan speed limit. Like Duct Static pressure setpoint reduction mentioned above, this DR strategy is relevant to fans with variable frequency drives (VFD). During the DR event, the speed of the VFD is limited to a fixed value. To be effective, the fixed value must be lower than if it were allowed to operate under normal closed loop conditions. Fan speed limiting saves energy for the same reasons as duct static pressure setpoint reduction. Its effect on the air distribution systems and associated occupied zones is somewhat less predictable because of the open-loop nature of the control. Fan speed limits may be useful as part of other DR strategies such as cooling system adjustments described below. This strategy may also be used on fans with inlet guide vanes (IGV).

Fan Quantity Reduction. For constant air volume fan systems, the only way to reduce fan energy is by turning fans off completely. This is obviously a severe reduction in service, although it may be of some use in common areas served by multiple fans. If such a strategy is used, it should be noted that cooling energy in the fans that remain on will increase to make up for those that are off.

Increase Supply Air temperature. This strategy saves mechanical cooling energy. In packaged direct expansion units and heat pumps, the savings will be achieved at each unit. For air handlers with cooling coils, the savings will occur at the central cooling plant. In either case, care must be taken to avoid increased fan energy in VAV systems due to increased air flow. This effect can be prevented by limiting fan speeds to levels in use prior to the increase in supply air temperature.

Central Chiller Plants. Most modern centrifugal, screw and reciprocating chillers have the capability of reducing their demand for power. This can be done by raising the chilled water supply temperature setpoint or by limiting the speed, capacity, the number of stages or current draw of the chiller. The quantity of chillers running can also be reduced in some plants.

Evaluation of Air Distribution and Cooling System Adjustment Strategies: While effective in terms of the ability to achieve load reductions, the use of centralized adjustments to air distribution systems and/or mechanical cooling systems for DR purposes have some fundamental drawbacks. In these strategies, the DR burden is not shared evenly between all the zones. Centralized, changes to the air distribution System and/or mechanical cooling systems allow zones with low demand or those that are closer to the main supply fan to continue to operate normally and hence not contribute toward load reduction in the facility. Zones with high demand, such the sunny side of the building or zones at the ends of long duct runs can become starved for air or otherwise go completely out of control. Centralized HVAC DR shed strategies can allow substantial deviations in temperature, airflow and ventilation rates in some areas of a facility. Increased monitoring of occupied areas should be conducted when using these strategies.

Lighting Based DR Strategies

Lighting systems offer great promise as a resource for DR shed savings for several reasons: 1) Lighting systems create a substantial electric load in commercial buildings, often more than 30% of the total. 2) Lighting has no rebound effect during the transition from DR events to normal operations. 3) The lighting systems in many California commercial buildings already have bi-level switching in place. Usually, this enables 1/3 or 2/3 or the lights in a given office to be turn off, leaving sufficient light for egress and many common office tasks.

However, there are major impediments to the use of lighting systems for DR: 1) Few office buildings have centralized control of lighting systems (Kiliccote, et al., 2005). 2) Even buildings with centralized lighting controls are not necessarily zoned in a way that would allow a reduction in lighting service that is adequate for occupancy.

Granularity of control is a very important factor in determining the usefulness of lighting systems for DR. The following lists five types of lighting systems from most coarse to most fine granularity: Zone Switching, Fixture Switching. Lamp Switching, Stepped Dimming, Continuous Dimming.

Zone Switching – In areas that are unoccupied or are illuminated by windows or other sources, entire lighting zones can be switched off for DR purposes. In some cases, this strategy can be applied to common spaces such as lobbies, corridors, and cafeterias.

Fixture/Lamp Switching - Fixture or lamp switching can be done by bi-level switching. California's Title 24 Energy Efficiency Building Standard requires multiple lighting level controls in all individual offices built since 1983. With bi-level switching, each office occupant is provided with two wall switches near the doorway to control their lights. In a typical installation, one switch would control 1/3 of the fluorescent lamps in the ceiling lighting system, while the other switch would control the remaining 2/3 of the lamps. This allows four possible light levels: OFF, 1/3, 2/3 and FULL lighting. The 2001 standards state that bi-level switching can be achieved in a variety ways such as:

- Switching the middle lamps of three lamp fixtures independently of outer lamps (lamp switching).
- Separately switching "on" alternative rows of fixtures (fixture switching)
- Separately switching "on" every other fixture in each row (fixture switching)
- Separately switching lamps in each fixture (lamp switching)

Step Dimming – Through the use of ON/OFF switches, controls to regulate the level of electrical light, step dimming is a popular energy-saving retrofit solution for applications where existing fixtures are not equipped with dimming ballasts. Stepped dimming is often called bi-level dimming because the strategy often involves two levels of light output, usually 100% and 50%. However, if more flexibility is required, stepped dimming can involve three levels of light output.

Continuous Dimming – Continuous dimming ballasts allow light output to be gradually dimmed over the full range, from 100% to 10% (fluorescent) or 100% to 50% (HID). These lighting systems provide an excellent resource for demand response purposes. These systems allow the lighting load to be reduced so gradually that modest changes may not even be noticed by building occupants (Akashi et al., 2003). Since the amount of reduction is continuously variable, specific DR shed goals can be achieved using straightforward strategies. As with global temperature adjustment, shed strategies using continuously dimming lighting can be implemented in an absolute (building-wide) or relative fashion.

In addition, to their use for demand response, dimmable ballasts can be used in the design of energy efficient systems that reduce electric light requirements when daylight is available. Also, when dimming is available, for many tasks occupants often prefer light levels that are less than 100%.

Evaluation of lighting for DR: The great potential for widespread use of lighting for DR will only be realized if more lighting systems are installed or upgraded to have the following features:

1) Centralized controls.
2) Zoning that allows light levels to be reduced with some degree of resolution that is minimally disruptive to building occupants.
3) Flexibility for various end-use scenarios.

Summary and Future Directions

This paper has presented a review of demand response control strategies in commercial buildings based on a combination of results from field studies in 30 buildings over a three year period. The field studies have shown that there is a significant opportunity to enable DR capabilities in many existing buildings using existing EMCS and lighting controls. Further research is needed to understand the prevalence of controls in existing buildings to support a broad based deployment of these strategies.

Newer, more advanced controls provide greater capability than older systems. Future work in this project will explore the applicability of these strategies to various building types, sizes, and climates.

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